

# ECONOMIC PRODUCTION RATE STUDY

Edward J. Downing, Jr., Gilbert E. Roesler, and William M. McGovern  
Advanced Technology, Inc.

## ABSTRACT

The Department of Defense Acquisition Improvement Program Action Number 7 stresses the need for each program manager to reduce the unit cost of his system by planning for and maintaining an economic production rate (EPR). The key elements in achieving an EPR are early planning and program stability. However, since stability is seldom possible, flexibility to accommodate a change to the production rate must be built into the plan. For this purpose and also to answer "what if" budget questions, it is important to have a model that relates rates of production with their corresponding estimated unit costs.

The objective of this study is to give the Program Manager tools for use in discussing, planning and evaluating economic production rates. In order to deal with large scale, multi-tiered acquisition programs, a distinction must be made between procurement and production rate. The economic procurement rate refers to the rate of acquisition of the complete system, while the economic production rate addresses each component or contractor contributing to the system. The EPR is defined as that rate of procurement (or production) that permits efficient use of available industrial resources to achieve the lowest unit cost. Using a model suggested by John Bemis, this study examines the procurement profile of five major DoD acquisition programs--the Army's M-1 tank, Fighting Vehicle System and TOW missile, the Air Force's A-10 aircraft, and the Navy's A-6E aircraft. The model can be expressed either graphically or as an exponential equation. The graphical form is especially useful when iso-unit cost lines are plotted on axes of production rate versus cumulative quantity. In this form it is possible to evaluate various procurement profiles of a system and draw some conclusions concerning their relative efficiencies. This analysis was done for each of the five systems, and savings from more economical rates are estimated.

## INTRODUCTION

This paper describes a 1982-83 Defense Systems Management College sponsored research study to examine economic production rate theory, its application to specific acquisition programs and the reasons why some systems are not produced at economic rates. A search of the literature uncovered no theoretically accurate models that could be

easily applied to an entire defense system and which used readily available data as input. Therefore, emphasis was placed on finding a workable, empirical model that could be used to relate unit cost to production rate.

The scope of this study was limited in two ways. First, the contractors' costs of production were proprietary and therefore unavailable. Second, the number of separately manufactured components of a large system was too great to evaluate them all, and the study generally was limited to variations in only the prime contractor's cost and production rate.

The systems selected for study were:

The Abrams M-1 Tank: a major Army system with a relatively high rate of production that is produced in a Government-Owned-Contractor-Operated (GOCO) plant. This presented an opportunity to study the aspects unique to that contracting method. (Prime contractor: General Dynamics)

Bradley Fighting Vehicle System: an Army system in production for only a short time. (Prime contractor: FMC)

A-6E Aircraft: a mature Naval aircraft with a low rate of production. (Prime contractor: Grumman)

A-10 Aircraft: an Air Force aircraft with a long history of production. (Prime contractor: Fairchild Republic Corporation)

TOW Missile: an Army system with a long history of production at a high rate. (Prime contractor: Hughes Aircraft Company)

On 14 December 1982, as a part of this study, a meeting was held at the Defense Systems Management College (DSMC), Ft. Belvoir, VA. Participants included representatives from the Office of the Secretary of Defense; the program offices of the systems selected for study; headquarters Army Materiel Development and Readiness Command (DARCOM); Headquarters, Air Force Systems Command (AFSC); Headquarters, Naval Air Systems Command (NAVAIR), the DSMC; several defense contractors directly involved with the systems under study; and Advanced Technology, Inc. The first draft of this study was reviewed and discussed by the participants. This meeting had a significant influence on the results of this study.

## EPR DEFINITION

The terms "procurement rate" and "production rate" are used almost interchangeably in this paper; however, because most defense systems are the products of a number of manufacturers, the term procurement is used in the following definition to convey the fact that the production rates of individual contractors result in an overall procurement rate for the system. The following is the definition put forward by this study:

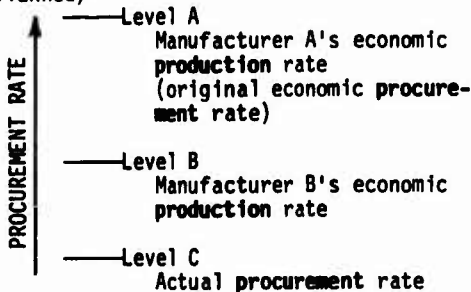
"The economic procurement rate of a system is the rate that permits efficient use of available industrial resources to achieve the lowest unit cost."

When applying this definition to a single manufacturer, the term "economic production rate" may be used.

During production planning for a system, it may be possible to establish a procurement rate that will efficiently utilize all the available resources of the manufacturers, even if it means providing additional funds to some of them in order to meet the agreed upon schedule. If all manufacturers optimize their industrial resources to that rate, it will be, by definition, the economic procurement rate, and all manufacturers will have economic production rates to match it. Usually, however, events lead to a separation of rates as shown below:

### EXAMPLE 1

higher rate  
(planned)



lower rate  
(actual)

In example 1, both manufacturer A and B are producing parts for a single system. The actual procurement rate of the system has fallen to Level C, far below the planned EPR at level A. The reason for the drop is not important to the example, but typically might be caused by a restriction of funds. Manufacturer A still has all of the resources to produce at Level A and retains A as its economic production rate, although this rate now comes from a production capacity in excess of the needs of the program. Manufacturer B has responded to the lower

required rate by diverting some resources to another job and now has a lower economic production rate, Level B. This is still higher than the rate required, but it is closer to the actual rate than Manufacturer A, and the government is paying a lower production rate penalty (proportionately) for Manufacturer B's product than for Manufacturer A's product. A pertinent question in this situation is, "What is the economic procurement rate of the system now?" Total industrial resources are not presently available to procure at a rate higher than Manufacturer B's rate (i.e., Manufacturer B's rate is limiting). Furthermore, because unit cost usually increases with a decreasing procurement rate (as will be discussed), it is uneconomical to procure at a rate less than Manufacturer B's rate. Manufacturer B's rate, therefore, is the present economic procurement rate and is the rate that corresponds to the lower economic production rate of the two major contractors.

For an individual contractor, the economic production rate is determined by a single industrial resource (tooling and test equipment, plant space, manpower and material) that limits production or assembly of the component being produced. An industrial resource becomes limiting when its capacity is fully utilized, while at the same time, excess capacity is available in the other industrial resources. To be considered "available" (for purposes of the EPR) the resources must be at the location needed, and their costs must fall within approved fiscal constraints.

## PLANNING FOR ECONOMIC PRODUCTION RATES

During the Full-Scale Development Phase of a program, a procurement schedule (rate) should emerge that considers operational requirements, life cycle cost, affordability, and other factors pertinent at the time, as well as a procurement rate that will efficiently use the industrial resources of the potential contractors. Furthermore, since an economic production rate will reduce the unit cost, rate might be a factor for negotiation. When a schedule is agreed upon, it becomes the basis for the contractor to optimize the levels of the industrial resources that will be applied to the production of that system. That is, production processes and tooling that are best suited to the chosen rate will be selected. Quantity of production, plant space, tooling and test equipment, manpower and materials (in the form of raw material, and subcontractor and vendor items) will be optimized to reduce unit cost. To the extent that this is accomplished, the EPR and the planned production rate will be the same. Later, however, circumstances may occur that will affect the actual schedule, as well as the EPR. For example, if all else remained

equal, but the government decided to stretch out production, the EPR would remain the same because the industrial resources would not be changed, but the actual production rate would decrease. This production rate decrease would result in a unit cost increase that, when multiplied by the total number of units produced, would be the penalty cost for producing at a rate lower than the EPR. If a contractor were able to reduce one or more of the resources that affect the EPR, such as giving up plant space to another job, the EPR would be lowered, bringing it closer to the actual production rate and reducing the penalty cost. The following examples will help to clarify these points.

EXAMPLE 2  
New Program

FSD Phase		Production Phase
Phase		
Level A	PRODUCTION RATE	A Planned +1
Original EPR (all contractors facilitate to this rate)		
Level B		B Actual rate (New EPR)
Preplanned -1		
Level C		C Planned -1
Preplanned -2		

In Example 2, Level A was the planned rate of procurement to which all contractors facilitated. Two lower preplanned rates, B and C were negotiated in case the procurement rate fell at a later time. These were to be used if, during the production phase, events (budget constraints, shortages of critical items, etc.) caused the actual procurement rate to fall. If they fell to level B, all contractors would shift to that level of production, and Level A would remain a higher (+1) option, and Level C would remain a lower (-1) option. Ideally, the contractors would use the excess capacity for other products, or they would reduce their resources by other means. Then, Level B would become the new EPR. Unfortunately, production resources are usually not that flexible. If they are not, the situation may be as shown in Example 3. Early in the production phase of Example 3 the actual procurement rate dropped from the original EPR at Level A to a lower procurement rate (Level D). The prime contractor and subcontractor both reduced their resources but were unable to reduce them to Level D. The prime contractor's economic production rate is at Level B, and the subcontractor's economic production rate is at level C (which, by definition is also the economic procurement rate). In this situation the cost penalty could be reduced, either by raising the level of actual procurement or by reducing production

EXAMPLE 3  
Mature Program

Early Production Phase		Later Production Phase
Level A	PRODUCTION RATE	A Original EPR
Original EPR		
Level B		B + 2
Prime		
Level C		C + 1
Sub (present EPR)		C1 Actual procurement and compromise EPR
Level D		D - 1
Actual procurement		

resources and lowering the contractor's economic production rate. In this example, Level C1 was agreed upon by the government and contractors as the target EPR acceptable to all. The contractors reduced their resources to optimize their production at that level, and the actual procurement rate was raised to that level. Levels B (+2), C (+1), and D (-1) remain as options. This, of course, represents an idealistic solution and a complete solution will never be as easy to realize in practice. Nevertheless, the problem of uneconomical production rates can be attacked by these methods.

Although this study uses the term EPR as though it were a single number, it is recognized that the complexities surrounding this subject make pinpoint accuracy impossible. Because industrial resources often come in discrete blocks, there may be a "break point" near the theoretical EPR that will be the practical EPR. This may become obvious only through a discussion with the contractor. However, this does not negate the importance of (a) an independent government estimate of the EPR, or (b) reporting the cost penalty caused by deviation from the EPR.

## MODELS

In finding the EPR for a system or contractor, the definition given above is important. At the theoretical EPR, there are no wasted industrial resources. At the practical EPR, wasted industrial resources are only minimized. The government can influence the level of resources during early planning; however, the government can discover the actual EPR only through discussions with the contractor. Of equal importance to establishing the EPR is the capability to estimate the change in unit cost that results from a shift in the rate of procurement or production. This estimating is done with the aid of a model.

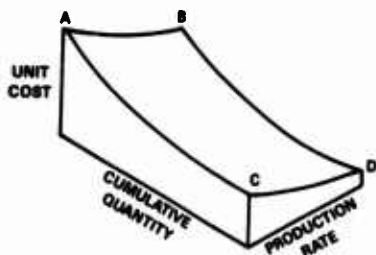
Classical microeconomics predicts the existence of a minimum unit cost as production rate increases (holding industrial resources constant). However, for defense systems, sufficiently high production rates to achieve this minimum are not normally attained during peacetime. Under-utilization of available capacity is normally one of the problems that must be addressed by the program manager. A model that describes the effect on unit cost of production rate change would be a valuable tool to him. The simplest such model is based on the fact that as fixed production costs are amortized over a greater number of units per time, raising the rate of production usually results in a lower unit cost (if the capacity of the facility is not exceeded). This relationship can be expressed as an inverse exponential relationship between unit cost and production rate.

J.C. Bemis (1), expanded a model by L.L. Smith and applied it to many DOD acquisition programs. His model takes the form:

$$UC = (k) Q^{-.xxx} R^{-.yyy}$$

where: UC = unit "fly away" cost of the Qth item produced at rate R. Constants k, .xxx and .yyy are determined by regression analysis of program data.

A physical model would appear as shown in Figure 1:

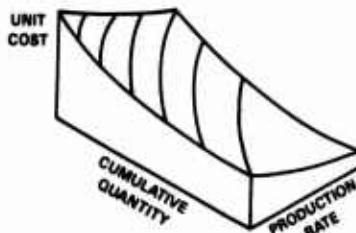


**BEMIS MODEL  
FIGURE 1**

The concave surface A B C D represents the solution to the equation. A is the highest point on the surface and corresponds to the cost of the first unit produced at the lowest production rate. It is also called the "prime unit cost." Note that curve AC is a cost improvement (learning) curve at the lowest production rate, and point A corresponds to the first unit cost of that curve. The surface is concave with point D being the lowest unit cost.

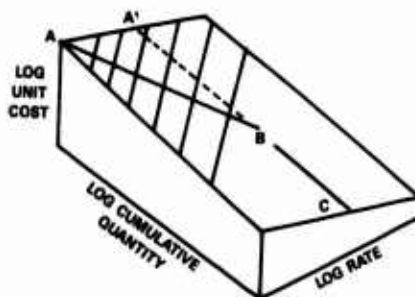
Another feature of the model takes advantage of the fact that unit cost can be lowered by increasing either cumulative quantity or production rate or both. Plotting combinations of cumulative quantity and production rate

that yield the same unit cost will describe an isocost line. In other words, all points on an isocost line will have the same unit cost. A family of isocost lines is shown in Figure 2 below.



**BEMIS MODEL WITH ISOCOST LINES  
FIGURE 2**

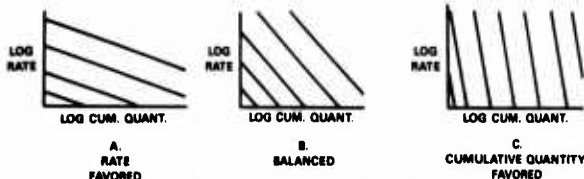
If the Bemis model is plotted using log values, a plane rather than a concave surface, will result and the isocost lines will be straight as shown in Figure 3. If a ball were placed at point A, in Figure 3 and were allowed to roll down the surface, it would follow the straight-line path AB.



**ROLLING BALL PATH AND EPR  
FIGURE 3**

AB is not the most economic path theoretically, but may be thought of as a practical path to follow during the build up stage of production. The most economical path A'C would be one that started at the highest possible rate (EPR), produced at that rate until the required quantity was reached and then stopped. For major DOD systems, this is not practical, and a planned build up to an EPR is required. However, once the Economic Production Rate (EPR) has been reached, it should be maintained until the end of production (BC in Figure 3). Some information on an efficient build up path can be gained by studying the isocost lines of a program.

The following three diagrams in Figure 4 show different patterns of isocost lines. In each pattern, the isocost lines farther from the origin represent lower unit costs than those closer to the origin. The objective, then, is to move as quickly as possible from the



ISOCOST LINE PATTERNS  
FIGURE 4

starting point (a point on the Y axis) to the lowest unit isocost line before most of the production occurs. Figure A, "Rate Favored," depicts a situation in which the slope of the rate curve is greater than the slope of the cumulative quantity (improvement) curve. A program with this type of graph is less adapted to long-term, low-level production than the other two cases. A low isocost line can be reached by rapidly increasing the production rate. This high rate should be maintained until the required quantity has been produced. On the other hand, a program with a graph such as C, "Cumulative Quantity Favored," is more adaptable to low-level production than a "rate favored" program. This is evident if one observes that isocost lines are cut more readily by emphasizing cumulative quantity, rather than by increasing production rate, even though both actions will reduce unit cost.

The Bemis (2) model has not been independently validated by a thorough study. His model is an extension of the L.L. Smith (3) equation that used direct labor hours per pound of airframe as the dependent variable. The high correlation factors, found over two years of working with the model, do suggest a relationship between unit flyaway cost and production rate, but correlations such as these could be caused by multicollinearity resulting from an interdependence between the independent variables of cumulative quantity and production rate.

#### LIMITATIONS ON PRODUCING AT THE EPR

Although the cost savings gained by procuring defense systems at the most economical rates may be substantial, they must be measured against other costs of a program. Procurement costs represent one

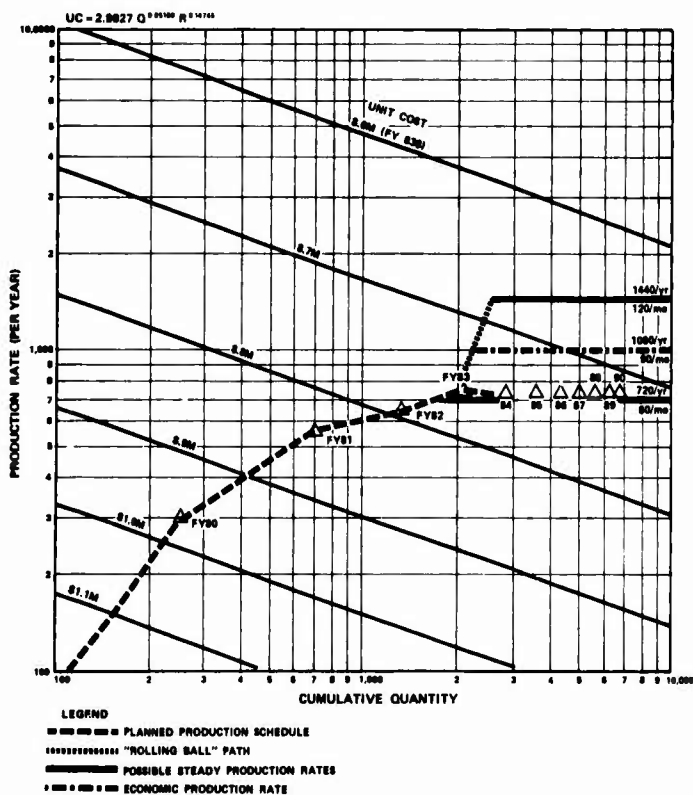
component of life cycle cost. Operating and support (O&S) costs, a large component of life cycle cost, will be affected by the rate of production. The decision-maker may be forced to choose between reducing immediate (small) production costs, or future (large) O&S costs.

There are other, noneconomic factors that may favor producing a product at a rate other than the EPR. These factors include maintaining a warm production base, a change in the threat, technical improvement or failure, and political considerations. These factors may dictate a specific rate of procurement, but they do not change the EPR.

#### PROGRAM ANALYSIS

Five defense acquisition programs were studied and their procurement profiles plotted against cumulative quantity and production rate. Regression analysis of cost-production data yielded an equation, in standard form, relating unit cost (UC), cumula-

#### ABRAMS M-1 TANK



M-1 ABRAMS TANK PRODUCTION RATE VS. CUMULATIVE QUANTITY  
FIGURE 5

tive quantity (Q) and production rate (R). Using this equation, iso-unit cost

lines were drawn to graphically show the procurement profile against unit cost. The economic production rates were arrived at through discussions with the program offices. Data were analyzed and graphed for all five programs, and the results are available in the final report. The discussion of the M-1 tank is presented as an illustration.

The graph and equation in Figure 5 show that the production of the prime contractor, General Dynamics, is rate favored. That is, the rate factor has a greater effect on unit cost than the cumulative quantity factor, and unit cost drops significantly with increasing rate of production. The three steady monthly production rates (60, 90, 120) were discussed during the history of the program; 90/month is the program office's estimate of facilitization and therefore the EPR. The planned production rate at present is 60/month. The estimated current dollar savings to be gained by producing at the higher rates are \$517M at 90/month and \$706M at a rate of 120/month if that rate could be achieved without major facilitization expense. It is important to note that the M-1 production facilities are government owned and contractor-operated; therefore, much of the fixed overhead costs will continue after the M-1 program is completed. If the facilities cannot be used or sold after the completion of the M-1 program, the savings will be reduced.

### CONCLUSIONS

The definition of EPR, as presented, covers most situations, is quantifiable, and gives practical results.

Program data showed excellent multiple correlations between log rate, log cumulative quantity, and log unit cost.

All production, including that intended for Foreign Military Sales (FMS), must be taken into account in determining the EPR.

The isocost lines derived from a regression analysis indicate the relative importance of the production rate and cumulative quantity to an item's production unit cost.

For the programs studied, the most common reason given for not being able to produce at the EPR was affordability. This was caused in part by the low priority of the defense systems (e.g., A-10) and a higher inflation than anticipated (e.g., FVS, M-1). In the case of the M-1, the cost of facilitization limited the EPR. Another reason for not producing at the EPR was to keep the production base warm until a replacement system had been designated (e.g., A-6E). Still another reason for a low rate of production was a stretch out of the production schedule caused

by a delay in identifying the requirement for a follow-on system (e.g., TOW).

### RECOMMENDATIONS

It is recommended that the definitions of economic production rate and economic procurement rate be accepted and disseminated throughout the defense acquisition community. EPR must be defined before the unit cost associated with it can be established.

In conjunction with the budget cycle, program offices should report the following information to their higher headquarters for evaluation and possible action to reduce unit cost:

1. Present and projected levels of procurement with associated unit costs.
2. Economic production rates of prime and major subcontractors.
3. The economic procurement rate for the system and the associated unit cost.
4. Contingency levels (with unit costs), higher and lower than the economic procurement rate, that will effectively use available or planned industrial resources.
5. Ways and means to reduce the average unit cost of the system by lowering the economic production rates of the contractors or raising the planned procurement rates of the system.

Production contracts should be written to anticipate changes in production rates and the quantity of the items to be produced. One approach would be to ask for a contractor commitment to costs at several rates. These preplanned rate levels would be similar to the -1 and -2 levels of Example 2.

Defense systems production data should be systematically collected for analysis of the possibility of cost savings and for validation and refinement of cost models. Presently such data are sparse and decentralized.

The Defense Acquisition Research Element (DARE) should sponsor a meeting of those persons who have contributed to the basic theory of EPR. The purpose of the meeting would be to find a bridge between EPR models that are theoretically accurate, but often impractical, and those that are practical, but theoretically weak.

### REFERENCES

1. J. C. Bemis, "A Model for Examining the Cost Implications of Production Rate," Concepts 4, No. 2 (Spring 1981), p. 85.
2. Ibid., p.85.
3. L.L. Smith, "An Investigation of Changes in Direct Labor Requirements," quoted in Bemis, "A Model for Examining the Cost Implications of Production Rate," p. 85.